# VI. *The Emission and Transmission of Röntgen Rays.*

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Of recent years much interesting work has been done to connect the atomic weight of an element with its power of emitting and transmitting various kinds of radiation. One may mention McClelland's* work on the secondary radiation given out by a substance exposed to the $\beta$ and $\gamma$ rays of radium, and Prof. J. J. Thomson's† results, which brought out the relation existing between atomic weight and the intensity of the emitted secondary Röntgen radiation. In each case an increase in atomic weight was accompanied by an increase in the amount of secondary radiation. Kleeman‡ has obtained a similar result in the case of the secondary radiation produced by the $\gamma$ rays from radium.

Benoist§ in 1901, working with the absorption by various elements of a definite beam of Röntgen rays, obtained a smooth curve approximating to a rectangular hyperbola by plotting atomic weight against a factor related to $\lambda/\rho$ (*i.e.*, the absorption of unit mass per unit area), where $\rho$ is the density of the screen, and $\lambda$ is the coefficient of absorption. $\lambda$ is defined by the exponential relation for a homogeneous beam $I = I_0 e^{-\lambda d}$, in which $I_0$ is the intensity of the incident beam, and I that of the emergent beam from a layer of thickness $d$. It follows from Benoist's curve that $\lambda/\rho$ increases with the atomic weight, and more rapidly in the region of low atomic weights. Crowther‖ measured the absorption by different elements of the $\beta$ rays from uranium, and obtained a periodic relation between atomic weight and $\lambda/\rho$.

It was thought that a careful study of the Röntgen radiation emitted by various

* McClelland, 'Sci. Trans. Roy. Dublin Soc.,' 1905 and 1906.

† J. J. Thomson, 'Proc. Camb. Phil. Soc.,' XIV., 1, p. 109, Nov., 1906.

‡ Kleeman, 'Phil. Mag.,' p. 618, Nov., 1907.

§ Benoist, 'Journal de Physique' (3), X., p. 653 (1901).

‖ Crowther, 'Phil. Mag.,' p. 379, Oct., 1906.

elements, when used as anticathodes in a discharge tube, might be repaid by the discovery of some sort of relation between their atomic weights and the quantity and quality of the Röntgen rays given out and transmitted under various conditions.

*Previous Work.*

It is, of course, known that the heavier metals, or rather, those of high atomic weight, make the most efficient anticathodes. RÖNTGEN* found that the rays from platinum are more intense than those from aluminium. CAMPBELL SWINTON† came to the conclusion that different metals emit Röntgen rays of the same penetrating power and in quantities which depend, but not very much, on the atomic weight. KAUFMANN‡ also showed a rough relation between atomic weight and intensity of radiation, and endeavoured without success to find a special connection between the rays from a metal and their penetrating power for screens of that metal. RÒITI'S work§ should also receive mention. All these observers used a photographic or fluoroscopic method of measuring intensities, and to their results can only be attached the accuracy which such methods permit. An ionisation method offers obvious advantages, and was naturally adopted in the present research.

Among the work on the transmission of Röntgen rays should be mentioned a paper by BENOIST and HURMUZESCU,‖ one by BENOIST¶ in addition to the one referred to above, and one by WALTER.** ADAMS,†† during the course of the present work, has worked on selective absorption, and HAGA,‡‡ during a research on the polarisation of secondary Röntgen rays, noticed selective absorption in the case of carbon and ebonite. An account of the earlier form of apparatus used by the writer, together with some preliminary results on "Selective Absorption," was given in May last year to the Cambridge Philosophical Society.§§

*Arrangement of Apparatus.*

The central portion of the beam of cathode rays passed down the metal tube T (fig. 1), and was incident on the anticathode at about 45°. A pencil of the Röntgen rays produced passed along the tube B, and out through the thin aluminium window W, into the ionisation chamber C. Both cathode and anode were of aluminium.

* RÖNTGEN, Würzburg, Stahel'scher Verlag, März, 1896.

† SWINTON, 'Proc. Roy. Soc.,' LXI., p. 222 (1897).

‡ KAUFMANN, 'Ver. Phy. Ges. Berlin,' XVI., p. 116 (1897).

§ RÒITI, 'Roma R. Accad. Lincei Rendic.,' VI., 2, p. 123 (1897).

‖ BENOIST and HURMUZESCU, 'Compt. Rend.,' Fév. 17, 1896.

¶ BENOIST, 'Compt. Rend.,' Jan. 18, 1897.

** WALTER, 'Ann. der Phys.,' XVII., p. 561 (1905).

†† J. M. ADAMS, 'Amer. Acad. Arts and Sciences,' XLII., p. 671 (1907); 'Phil. Mag.,' XIII., p. 576 (1907); 'Phys. Rev.,' XXVI., p. 202 (1908).

‡‡ HAGA, 'Ann. der Phys.,' XXIII., p. 445 (1907).

§§ KAYE, 'Proc. Camb. Phil. Soc.,' XIV., p. 236, May, 1907.

A plane cathode was employed so that there was no focussing of the cathode rays ; the object was to avoid an undue rise of temperature of the anticathode with the consequent liberation of gas.

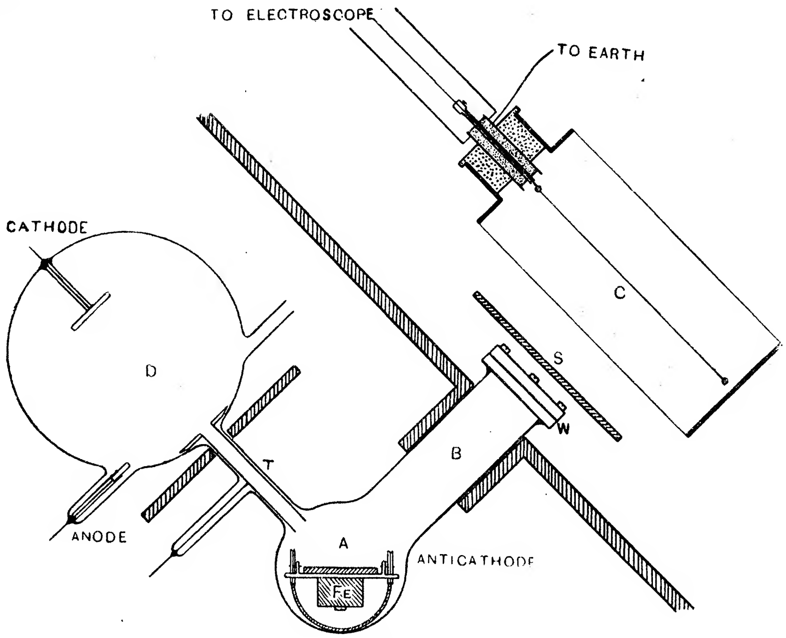


Fig. 1.

The elements used as anticathodes were mounted in line on a car made of aluminium which ran along horizontal rails fastened by sealing-wax to the bottom of the tube A. The rails consisted of one-half of a piece of aluminium tube cut along its length from end to end. Underneath each axle of the car was fastened a piece of soft iron, and by means of a small electro-magnet outside, the car could be moved and any metal desired brought under the beam of cathode rays.

*Anticathodes and Screens.*—The anticathodes were about 2 cms. diameter, 2 mms. thick, and were kept in position by small pins let into the body of the car. Some twenty elements were employed as radiators. The metals platinum, tantalum, tin, cadmium, silver, palladium, zinc, copper, nickel, iron and aluminium had their surfaces cleaned and polished where necessary, first with emery of different grades, and, finally, with jewellers' rouge. The lead, thallium, and calcium surfaces were renewed by planing or filing immediately before sealing up the tube. The elements bismuth, tungsten, antimony, chromium and magnesium were used in the form of powder. For these, small trays were spun in a lathe out of thin aluminium sheet, and into them the powders were packed tightly, their upper surfaces flush with the rims. A disc of gas carbon was used for the carbon anticathode.

I owe the tantalum to the kindness of Messrs. Siemens and Halske, who were good enough to provide me with a suitable specimen.

Screens of aluminium, iron, nickel, copper, zinc, silver, tin, platinum, and lead were employed, and the thickness was in every case determined by weighing. Platinum

leaf (0·000025 cm. thick), silver leaf (0·00002 cm. thick), copper leaf (0·000042 cm. thick), and aluminium leaf (0·00001 cm. thick) were obtained from Nuremberg, and were piled for screens of thickness less than about 0·001 cm. Above this thickness rolled samples of metal sheet could be procured in most cases.

*The Discharge Tube.*—The whole anticathode system was earthed and put in metallic connection with the anode and the tube T. The discharge was generated by a 10-inch Cox induction coil. Across the electrodes an adjustable spark gap, consisting of two polished brass balls 2·54 cms. in diameter, furnished a rough measure of the potential difference, as given by ORGLER'S formula,*

$$V = 28{,}000d,$$

where V is the potential difference in volts, and $d$ is the spark length in centimetres.

A Villard rectifier in circuit prevented reversals of the discharge. The discharge tube was connected to a Töpler pump, a McLeod gauge, and a $P_2O_5$ bulb.

In the earlier stages of the work a good deal of trouble was caused by the slow and steady evolution of gas from the considerable mass of metal in the tube, which necessitated much tedious and laborious pumping and delayed the taking of readings.

In later work a cocoanut charcoal tube which could be surrounded by liquid air was mounted on the apparatus, and a barometric mercury cut-off was placed between this and the discharge tube. This arrangement enabled the gases which had been liberated by the discharge and absorbed by the charcoal to be pumped off at leisure.

The metal tube T was not present in the earlier form of apparatus, and its introduction proved of great value in two directions. Firstly, it prevented the excessive metallic deposition on the walls of the tube in that region, which formerly unfitted the apparatus for use. Secondly, it was employed as a temporary cathode, the other electrode being the anticathode system. A tube-cathode concentrates the cathode rays along its axis, so that a beam of rays was obtained intense enough to raise the point of impact on the anticathode to a white heat in the case of some of the powdered elements. By means of a small magnet this point of incandescence could be moved about over the surface of the anticathode, and the rate of evolution of the gas in the metals was so greatly increased that it did not take very long to reach a state when a discharge, using the normal electrodes, caused but little alteration in the vacuum.

After some weeks' use the bulb lost all inclination to soften and would tend to harden considerably during the course of a long run: the absorbed gas would usually be expelled again if the bulb were given a rest. Occasionally, too, it would happen that one anticathode would harden the bulb, while another would soften it. Platinum, it was noticed, almost always tended to harden the tube. After running for an hour or so, however, matters would usually adjust themselves, and useful measurements could be made if they were taken at definite intervals. The tendency of the bulb to harden

* ORGLER, 'Ann. der Physik,' I., p. 159 (1900).

was largely diminished by using the least current in the primary circuit of the coil, which would just cause the discharge to pass in the tube.

The vacuum could, however, be kept very fairly constant by keeping the apparatus joined to the charcoal tube, and disposing and maintaining the level of the outside liquid air until a convenient working pressure was arrived at.

Another and excellent plan, which was latterly always adopted, is to saturate the charcoal with gas at the pressure desired, and keep it entirely immersed in the liquid air. By this means the pressure can be maintained constant for hours together, no matter how intense the discharge.

In a comparison of the Röntgen rays from different metals it is, of course, essential to keep the current in the primary circuit of the coil constant, and an ordinary hammer-break interrupter cannot be relied upon to do this. A mercury turbine interrupter working in spirit was used. It proved reliable if periodically cleaned, and worked more steadily at high than at low speeds. Any small variations indicated by the ammeter in the primary circuit could be followed and corrected for by an adjustable resistance. An increase in the current through the primary, besides increasing the intensity of the Röntgen rays, has also the effect of augmenting the length of the equivalent spark gap of the tube.

The aluminium window was 0·0065 cm. thick, and 2 cms. in diameter, and perceptibly sagged under the outside pressure. It was gripped between two stout brass rings screwed together. One of the rings was slipped on to the glass tube B, and the joint was completed with sealing-wax.

The ionisation vessel consisted of a flat cylinder about 9 cms. diameter and 4 cms. deep, with its ends covered with aluminium leaf. The middle of the front face was about 4 cms. from the aluminium window. A central insulated aluminium ring, over which was stretched aluminium leaf, was mounted with its plane parallel to the ends of the cylinder. It was insulated by sulphur in an earthed guard tube which was mounted in an ebonite plug let into the side of the cylinder. The connection to the gold leaf of a Wilson tilted electroscope E (fig. 2) was shielded by earthed tubes. The outside of the ionisation chamber was raised by means of a battery of small accumulators, with the negative pole earthed, to a potential (200 volts) sufficient to give a saturation current for any type of Röntgen ray. A lead enclosure shielded the electroscope, and another surrounded the discharge tube.

### *Measurements.*

The very great range in sensitiveness that a tilted electroscope provides was a great convenience in the present work, owing to the large variations in intensity of the rays dealt with. A potential divider, P, giving a control of a fraction of a volt, was used to furnish a fine adjustment on the potential of the charged plate of the electroscope, which ordinarily was raised to something in the neighbourhood of 200 volts.

A calcium-chloride solution key, K, which was operated from a distance, made or broke the earth connection to the gold-leaf system.

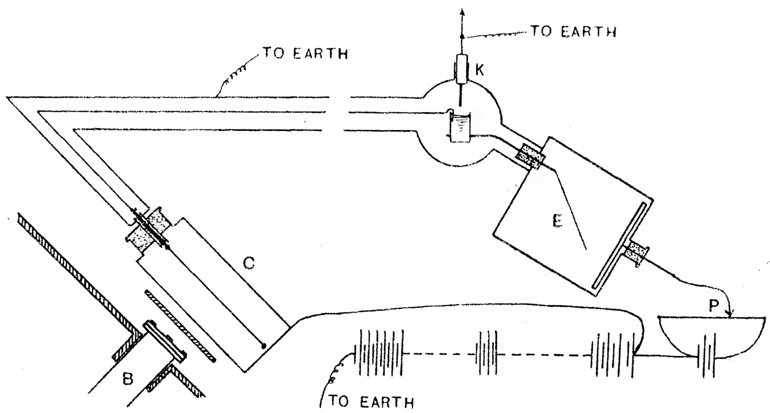


Fig. 2.

The gold leaf of the electroscope was viewed through a low-power microscope, having a scale in the eye-piece. Its time of travel over a definite range was taken with a stop-watch, and was usually from 20 to 60 seconds. When things were working well, an accuracy of 1 per cent. could be obtained. In a comparison of the radiations from a pair of metals, they were used alternately until the readings were concordant.

Before the mercury-break was employed, a standard bulb with a platinum anticathode was joined in series with the experimental one. It was provided with an ionisation chamber and electroscope, and thus served as a check on the constancy of the current passing through the two bulbs. But if the mercury-break was working well, the use of this standard bulb was not found to be necessary.

## *Results.*

The results for the aluminium, copper, and platinum screens will be discussed fully, and may be regarded as typical of the rest.

Of the anticathodes, aluminium, iron, nickel, copper, silver, platinum, and lead received special attention.

*Rays direct from Aluminium Window.*—With a potential difference of 28,000 volts on the tube the relative ionisation values for the rays emerging from the aluminium window unobstructed by any screen are given in the table below for some of the radiators. The value for platinum is made equal to 100.

These radiation values, although they do not follow the order of the atomic weights, divide themselves into four well marked groups—Bi to Ta, Sn to Pd, Zn to Fe, and Ca to C. The metals of the iron-zinc group are characterised by abnormally high radiation values. BARKLA and SADLER,* working with secondary Röntgen rays, have arrived at a grouping almost identical, and characterised by similar features.

* BARKLA and SADLER, 'Nature,' p. 344, Feb. 13, 1908.

| Radiator. | Atomic weight. | Radiation value. | Radiator. | Atomic weight. | Radiation value. |
|---|---|---|---|---|---|
| Bi | 208·5 | 86 | Zn | 65 | 79 |
| Pb | 207 | 93 | Cu | 63·6 | 89 |
| Tl | 204 | 89 | Ni | 58·7 | 90 |
| Pt | 197 | **100** | Fe | 56 | 83 |
| Ta | 183 | 110 | Ca | 40 | 19 |
| Sn | 119 | 48 | Al | 27 | 14 |
| Cd | 112 | 47 | Mg | 24·4 | 13 |
| Pd | 106·5 | 49 | C | 12 | 5 |

STARKE* measured the relative numbers of secondary cathode particles emitted by different metals under the bombardment of a beam of cathode rays. It is of interest to compare his results with the corresponding ones of those just quoted.

| Radiator. | Atomic weight. | Emitted cathode rays. | Emitted Röntgen rays. |
|---|---|---|---|
| Pt | 197 | **100** | **100** |
| Pb | 207 | 88 | 93 |
| Bi | 208·5 | 81 | 86 |
| Ni | 58·7 | 67 | 90 |
| Cu | 63·6 | 63 | 89 |
| Fe | 56 | 56 | 82 |
| Zn | 65 | 56 | 79 |
| Al | 27 | 35 | 14 |
| Mg | 24·4 | 34 | 13 |

The order, which is not that of the atomic weights, is, with one exception, the same in both cases. The absorption of the softest Röntgen rays by the aluminium window probably explains part of the lack of quantitative agreement, especially with the radiators of low atomic weight. We have, too, to remember that we are measuring, by an ionisation method, the intensities of heterogeneous beams of rays, the components of which have very different ionising powers. The general resemblance of the two lists is, however, sufficiently noteworthy.

To bring out any peculiarities in the radiation from any of the anticathodes the ionisation values given by the electroscope are taken relative to that of one of the metals—platinum (which is kept constant and equal to 100 for all screens). These relative values are plotted as ordinates against thickness of screen. Thus the graph of the platinum radiation is a horizontal straight line, and if all the radiations were similar in composition they would be represented by parallel straight lines.

Figs. 3, 4, and 5 are thus obtained, and show how the Röntgen rays from lead, platinum, silver, copper, nickel, iron, and aluminium, generated under a potential difference of about 28,000 volts, are dealt with by screens of aluminium, copper, and

* STARKE, 'WIED. Ann.,' LXVI., p. 49 (1898); 'Ann. der Phys.,' III., p. 75 (1900).

platinum respectively. The percentage transmitted, of the radiation from platinum, is indicated for various thicknesses of screen.

It ought to be mentioned that the silver anticathode soon amalgamated with the mercury vapour from the pump, and its surface thus became coated with an alloy of the probable composition Ag.Hg.

*Aluminium Screens.*—Consider fig. 3. As the thickness of aluminium screen is increased, lead and silver increase their radiation values, and take places warranted by their atomic weights. Thus the softest rays due to a lead or silver radiator are more penetrating to aluminium than the softest rays from platinum.

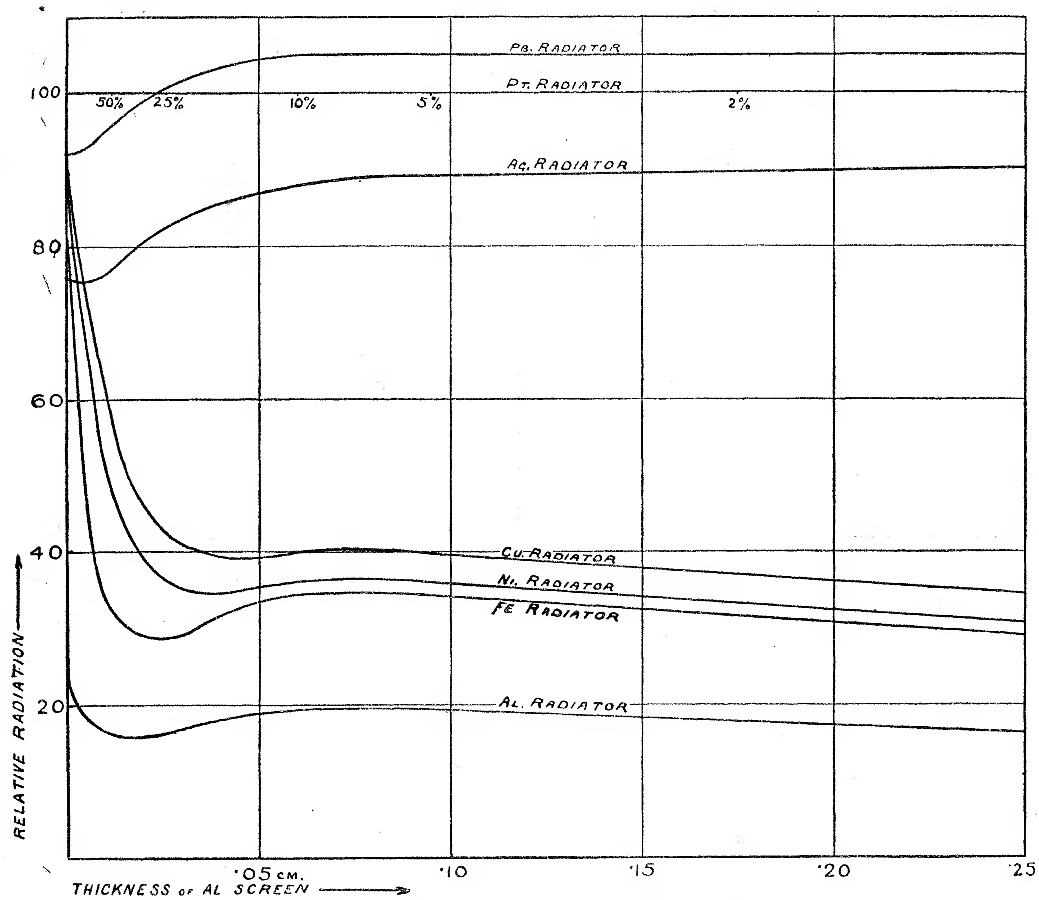


Fig. 3. Aluminium screen, 28,000 volts.

The metals of the iron group—copper, nickel, and iron—rapidly lose, with thicker screens, their initially high radiation values. Together with aluminium they afterwards show weak maxima at a thickness of about 0·07 cm. of screen. Thus for the range 0·03 to 0·07 cm. the rays from these metals are more penetrating to aluminium than are the rays from platinum, and we thus have a region over which selective transmission is manifested.

It will be noticed that for screens thicker than about 2 mms. an alteration in the thickness produces very little change in the relative amounts of radiation from the

different metals. The inference is that all the beams are now similar in composition, and we should therefore be justified in expecting, at this stage, some evident relation between intensity and the atomic weight of the radiator. The point is gone into later (p. 135), but it may be stated at once that the two are roughly proportional.

*Copper Screens.*—If we now consider the case of the copper screens (fig. 4), we see at once how very different the transmission curves are from those where an aluminium

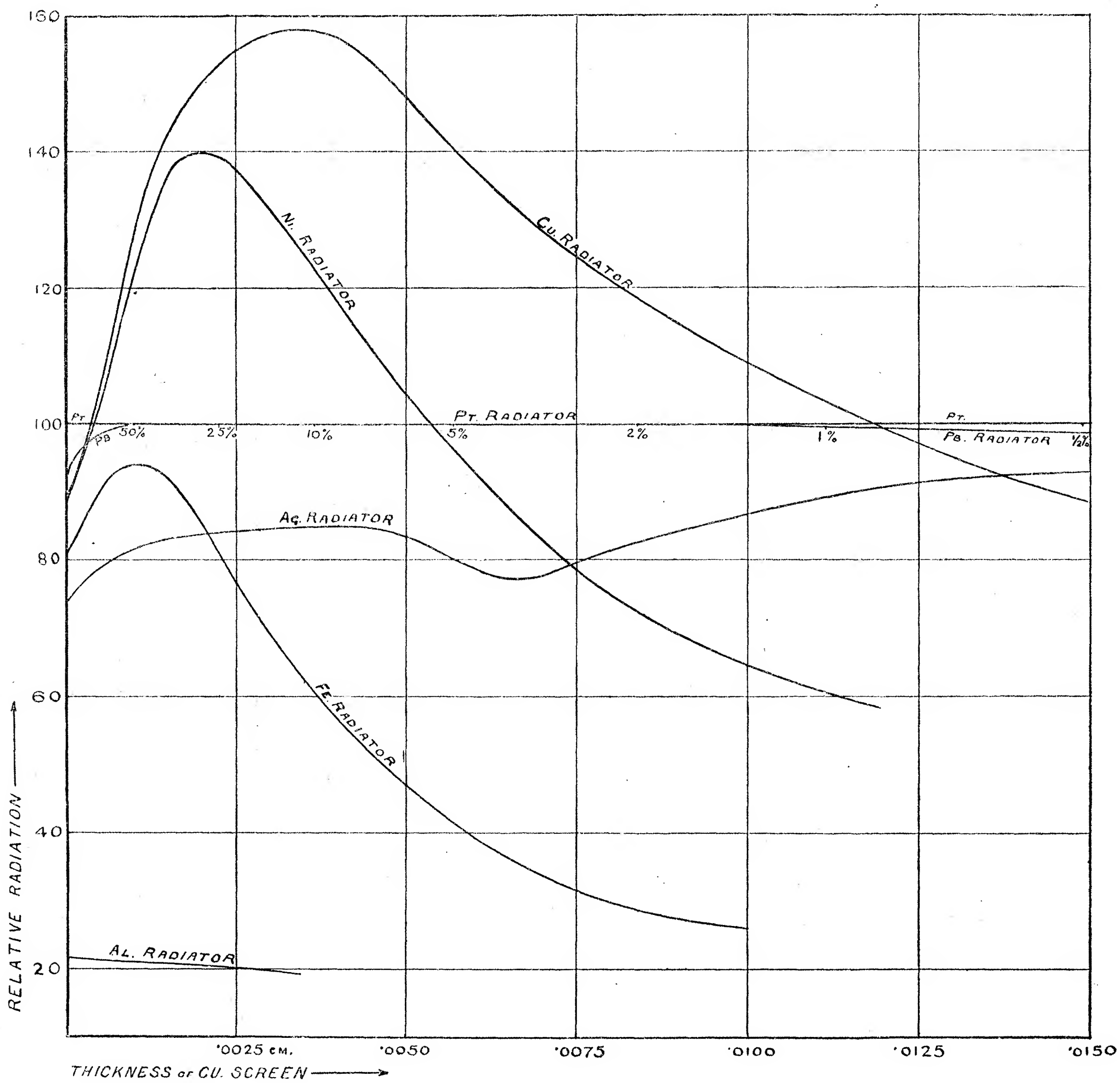


Fig. 4. Copper screen, 28,000 volts.

screen was used. As the thickness of screen is increased, silver and lead rise into place as before, but iron, nickel, and copper now increase their values and form well-marked maxima. Over a considerable range, when anticathodes of copper and nickel are used, more radiation emerges from a copper screen than is the case when the anticathode is of platinum or lead, although the latter have much higher atomic weights.

It will be noticed that the nearer the atomic weight of the radiator is to that of copper, the more marked and extensive is the maximum.

The higher the atomic weight, the thicker is the screen at which the peak of the curve occurs. The diagram provides a good indication of the amount of radiation specially penetrating to copper which is present in each case. The resemblance between the radiations from nickel and copper, especially for the thinner screens, is noticeable. The case of silver is interesting. As mentioned above, its surface became

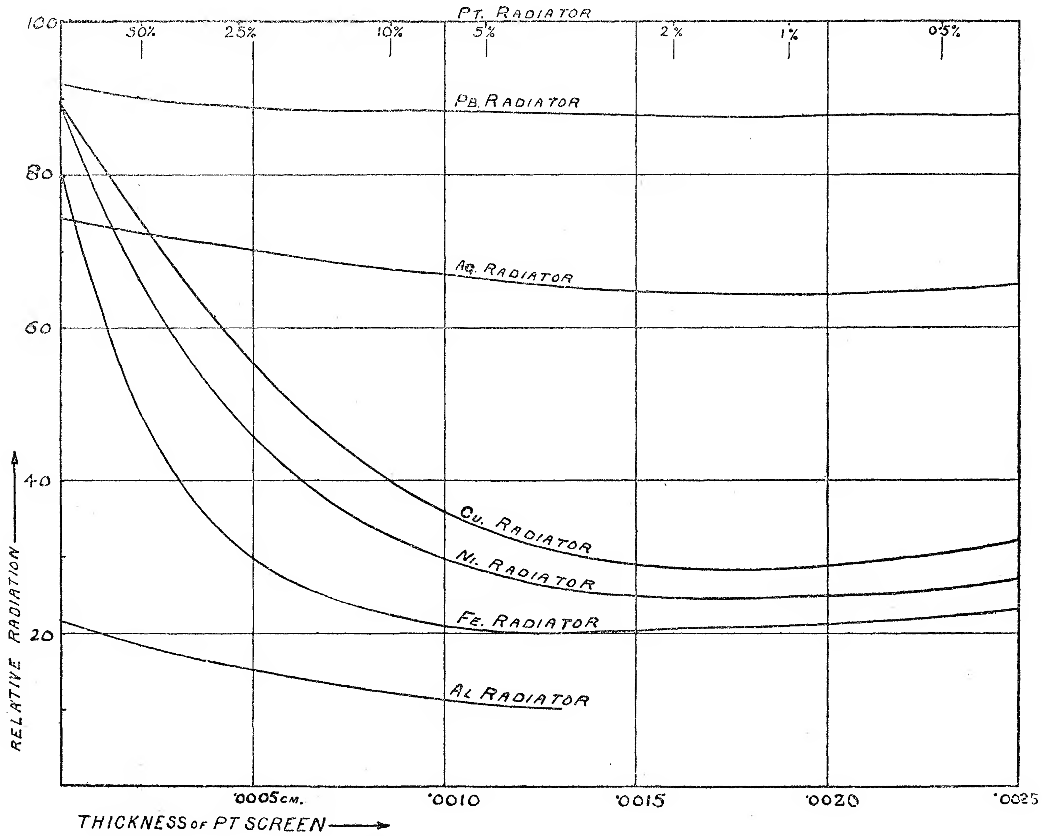


Fig. 5. Pt screen, 28,000 volts.

amalgamated, and hence its radiation could be expected to show features indicative of both silver and mercury. This is the explanation of why the graph shows a first weak maximum, due to silver, and afterwards rises again owing to the presence of the mercury.

With the thickest copper screens there is every indication that, just as with screens of aluminium, the relative values for the penetrating radiations eventually follow the order of the atomic weights of the radiators, though even with the thickest screens tried the value for the copper radiation is still distinctly relatively higher than with the aluminium screens.*

* This gradual dying away of the selective transmission, as the rays increase in hardness, is in accordance with the behaviour of the $\gamma$ rays, which ignore atomic structure.

*Platinum Screens.*—If we now turn to the transmission curves secured under the same conditions with platinum screens (fig. 5), we see in the main a resemblance to those obtained with aluminium screens, but with some differences. The radiation value for lead is now throughout about 10 per cent. less than that of platinum, but with the thickest screens the two curves show some signs of approaching. It is *à propos* to notice here that if screens of lead are used, then the radiation value of lead is about 5 per cent. larger than that of platinum for screens of all thicknesses except the very thinnest.

Thus platinum and lead show the phenomenon of selective transmission very nicely.

With platinum screens the radiation curves for copper, nickel, and iron show very flat minima—a result consequent on the radiation value of platinum being kept constant. Platinum thus shows a not very marked selective transmission over this range. Speaking generally, the radiation values with a platinum screen are lower than the corresponding ones with an aluminium screen.

The comparative effect of the three screens—aluminium, copper, and platinum—on the different radiations is exemplified in the following table. For ease of comparison the screens have been chosen of thicknesses which cut down the platinum radiation by the same amount in each case.

| Radiator. | Percentage of radiation transmitted by— | | |
|---|---|---|---|
| | 0·17 cm. Al. | 0·008 cm. Cu. | 0·0015 cm. Pt. |
| | per cent. | per cent. | per cent. |
| Pt | 2·5 | 2·5 | 2·5 |
| Cu | 1·0 | 3·1 | 0·8 |
| Ni | 0·98 | 1·9 | 0·7 |
| Fe | 0·94 | 0·8 | 0·6 |

*Iron, Nickel, and Zinc Screens.*—Still using the same conditions of experiment, measurements of the relative radiations from the different anticathodes were made with screens of iron, nickel, and zinc.

It will be sufficient to say that in each case the curves of transmission are similar to those for screens of copper.

When screen and anticathode are alike or have adjoining atomic weights, the radiation is, over a certain region, largely augmented relative to that from any other anticathode. The more remote the atomic weights of the radiator and screen, the more limited is this region, and the sooner does the anticathode assume a normal radiation value, judged on an atomic weight basis. Generally speaking, the lower the atomic weight of the radiator in a group, the thinner is the range of screens of like metal for which its radiation shows abnormal penetrability. It would seem, therefore,

that, as the atomic weight of the metal of the screen increases, the harder are the rays for which it shows selective transmission.

*General Comparison of Screens.*—The following selected values of the relative radiations will give a notion as to the degree and extent of the selective transmission shown by different screens under the same conditions. As before, the radiations are taken relative to that of platinum.

| | | Al screen. | | Fe screen. | | Ni screen. | | Cu screen. | | Zn screen. | | Pt screen. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Percentage of Pt radiation transmitted | | 9 per cent. | 2 per cent. | 9 per cent. | 2 per cent. | 9 per cent. | 2 per cent. | 9 per cent. | 2 per cent. | 9 per cent. | 2 per cent. | 9 per cent. | 2 per cent. |
| Atomic weight. | Radiator. | | | | | | | | | | | | |
| 207 | Pb | 105 | 107 | 99 | 104 | 100 | 102 | 100 | 102 | 100 | 101 | 88 | 86 |
| 195 | Pt | **100** | **100** | **100** | **100** | **100** | **100** | **100** | **100** | **100** | **100** | **100** | **100** |
| 108 | Ag | 89 | 90 | 84 | 90 | 79 | 90 | 82 | 88 | 80 | 90 | 67 | 64 |
| 63·6 | Cu | 39 | 34 | 45 | 41 | 170 | 60 | 156 | 120 | 95 | 63 | 40 | 28 |
| 58·7 | Ni | 35 | 30 | 43 | 45 | 155 | 55 | 120 | 75 | 80 | 39 | 33 | 24 |
| 56 | Fe | 31 | 28 | 131 | 49 | 72 | 33 | 80 | 32 | 50 | 25 | 24 | 22 |
| 27 | Al | 19 | 12 | 22 | 15 | 21 | 14 | 21 | 15 | 21 | 15 | 15 | 11 |

Apart from the points already mentioned, the most interesting feature is the nearness of the radiation values of nickel and copper and the remoteness of those of nickel and iron when the thinner of each pair of metal screens is in use. This is especially apparent with both thicknesses of the iron, nickel, and copper screens. BARKLA and SADLER* working with secondary Röntgen rays have obtained similar results and claim a higher value for the atomic weight of nickel than the one usually accepted. It should, however, be noticed that with the thicker screens, especially those of aluminium and platinum (and it may be added silver and tin), there is a distinct tendency for nickel to move into a place justified by its accepted atomic weight. It was hoped that light would be thrown on the subject by using a cobalt anticathode, but unfortunately the two samples of cobalt used turned out to be unsatisfactory and gave much too low a radiation value for all screens. The question is referred to later (p. 139).

The values obtained with silver and tin screens resemble those obtained with platinum screens. The very large augmentation in the transmitted radiation when screen and radiator are alike is confined to the metals of the chromium-zinc group. For other metals the effect is much smaller.

The general conclusion may be drawn that of all the screens tried aluminium shows

* BARKLA and SADLER, 'Phil. Mag.,' p. 409, Sept., 1907.

the least anomalous features in its transmission of any of the radiations. It would seem, therefore, to be the most suitable material to use in determining the penetrating power of a beam of rays.

### *Atomic Weight of Radiator and Intensity of Rays.*

It was noticed on p. 130 that for aluminium screens thicker than about 2 mms. very little change in the relative amounts of radiation from the different anticathodes is caused by an alteration in the thickness of the screen. We are evidently here dealing with beams of hard rays of similar composition.

Under these conditions the intensity of the radiation, from a number of elements, was measured, and the values are tabulated below. The Röntgen rays used were generated under a potential of about 22,000 volts, and a screen of aluminium about 2 mms. thick was employed; it cut down the initial radiation about 150 times. The results are given below; the radiation values are relative to that of platinum. The value for silver is calculated from that of the amalgam Ag.Hg, using a value for mercury obtained from fig. 6 by interpolation.

| Atomic weight. | Radiator. | Intensity of radiation. | $\frac{\text{Radiation}}{\text{Atomic weight}}$. |
|---|---|---|---|
| 208·5 | Bi | 112 | 0·53 |
| 207 | Pb | 109 | 0·53 |
| 204 | Tl | 104 | 0·51 |
| 195 | Pt | **100** | 0·51 |
| 184 | W | 91 | 0·50 |
| 183 | Ta | 90 | 0·49 |
| 120 | Sb | 63 | 0·53 |
| 119 | Sn | 60 | 0·50 |
| 112 | Cd | 57 | 0·51 |
| 108 | Ag | 56 | 0·52 |
| 106·5 | Pd | 55 | 0·52 |
| 65 | Zn | 35 | 0·54 |
| 63·6 | Cu | 33 | 0·52 |
| 58·7 | Ni | 30 | 0·51 |
| 56 | Fe | 27 | 0·48 |
| 52 | Cr | 25 | 0·48 |
| 40 | Ca | 16 | 0·40 |
| 27 | Al | 11 | 0·41 |
| 24·4 | Mg | 10 | 0·41 |
| 12 | C | 5 | 0·42 |

It will be seen that atomic weight and intensity of radiation increase together, the latter a little more rapidly than the former. With higher potentials on the tube, the metals of high atomic weight increase their radiation values relative to those of the lighter elements. In fig. 6 the above intensities are plotted against atomic weight.

The curve presents some resemblances to those obtained by Prof. J. J. THOMSON* when working on secondary Röntgen rays. He also found less difference between the amounts of secondary radiation from a metal of low atomic weight and one of high when the incident rays were soft than when they were hard.

To regard the intensity of radiation as proportional to the atomic weight of the anticathode is a good rough working rule. The curve has been used to obtain the intensities of the radiation for intermediate elements.

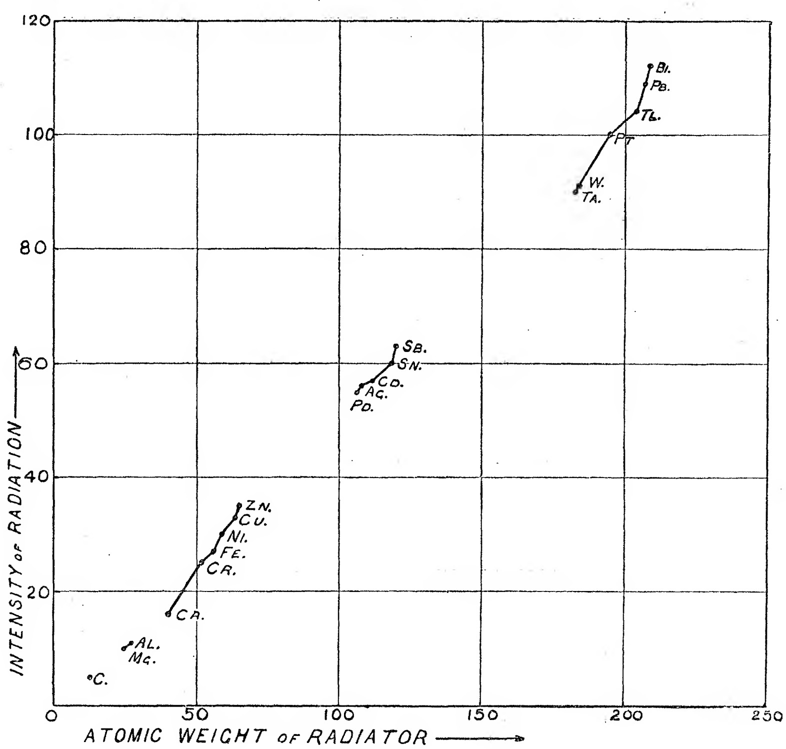


Fig. 6.

The list below gives the radiation values and the latest determinations of the melting points (where known) of those elements which by reason of their refractoriness may be regarded as suitable for the anticathode of a focus tube. The physical properties of some of them are not convenient, and to others the scarcity and consequent price are at present an insurmountable objection. Tantalum is now being used in Röntgen bulbs. Its radiation is rather richer than platinum radiation in soft rays, and it emits about 10 per cent. less hard rays than platinum. It has the advantage of a much higher melting point, and appears not to harden the tubes so much as platinum on continued running. All the metals of this group would make excellent anticathodes. Generally speaking, the lower the atomic weight the larger the proportion of soft rays (or, rather, rays not transparent to aluminium) in the radiation. This is especially the case with the metals of the iron group.

* J. J. THOMSON, 'Proc. Camb. Phil. Soc.,' XIV., 1, p. 109, Nov., 1906.

| Metal. | Atomic weight. | Intensity of radiation. | Melting point. |
|---|---|---|---|
| | | | ° C. |
| Uranium | 238·5 | c. 125 | — |
| Thorium | 232·5 | c. 120 | — |
| Gold | 197 | 101 | 1064 |
| Platinum | 195 | **100** | 1750 |
| Iridium | 193 | 98 | 2250 |
| Osmium | 191 | 97 | 2200 |
| Tungsten | 184 | 91 | 3080 |
| Tantalum | 183 | 90 | 2910 |
| Ytterbium | 173 | 86 | — |
| Thulium | 171 | 85 | — |
| Erbium | 166 | 83 | — |
| Terbium | 160 | 80 | — |
| Gadolinium | 156 | 78 | — |
| Samarium | 150 | 76 | 1350 |
| Palladium | 106·5 | 55 | 1540 |
| Rhodium | 103 | 54 | c. 2000 |
| Ruthenium | 102 | 53 | 1900 |
| Molybdenum | 96 | 50 | — |
| Niobium | 94 | 49 | 1950 |
| Zirconium | 90·6 | 47 | c. 1300 |
| Yttrium | 89·0 | 46 | — |
| Copper | 63·6 | 33 | 1084 |
| Cobalt | 59·0 | 30 | 1460 |
| Nickel | 58·7 | 30 | 1430 |
| Iron | 56 | 27 | 1500 |
| Manganese | 55 | 26 | 1200 |
| Chromium | 52 | 25 | 1490 |
| Vanadium | 51 | 24 | 1620 |
| Titanium | 48 | 22 | c. 2500 |

## *Penetrating Powers of the Radiations.*

So far attention has been directed more to the relative intensities than to the penetrating powers of the different radiations. A new series of experiments was carried out with a potential on the tube of about 20,000 volts. The anticathode was not changed until a complete set of measurements of the intensity of the rays had been made for all the different thicknesses of a metal screen. Figs. 7, 8, and 9 are derived from the results obtained by inserting screens of aluminium, copper, and platinum in the paths of the radiations from aluminium, iron, nickel, copper, and platinum. The thickness of screen is plotted against $\log_{10} \frac{I}{I_0}$, where $I_0$ is the initial intensity of the beam as it leaves the aluminium window, and I its intensity after transmission through a screen. The slope of the tangent to the curve at any point gives (when multiplied by 2·3) the value of the coefficient of absorption ($\lambda$) at that region. $\lambda$ is defined by the relation $I = I_0 e^{-\lambda d}$, where $d$ is the thickness of screen at the point. If the relation is homogeneous over any region, the graph will, of course, be a straight line.

*Aluminium Screens.*—Turning to fig. 7 (aluminium screens), we notice a general resemblance between the curves for platinum, copper, nickel and iron radiators. They indicate the kind of absorption usual with Röntgen rays—that is, the coefficient of absorption steadily diminishes with increasing thickness of screen. The four curves become practically parallel with the thickest screens. The proximity of the early portions of the nickel and copper radiation curves will be noticed.

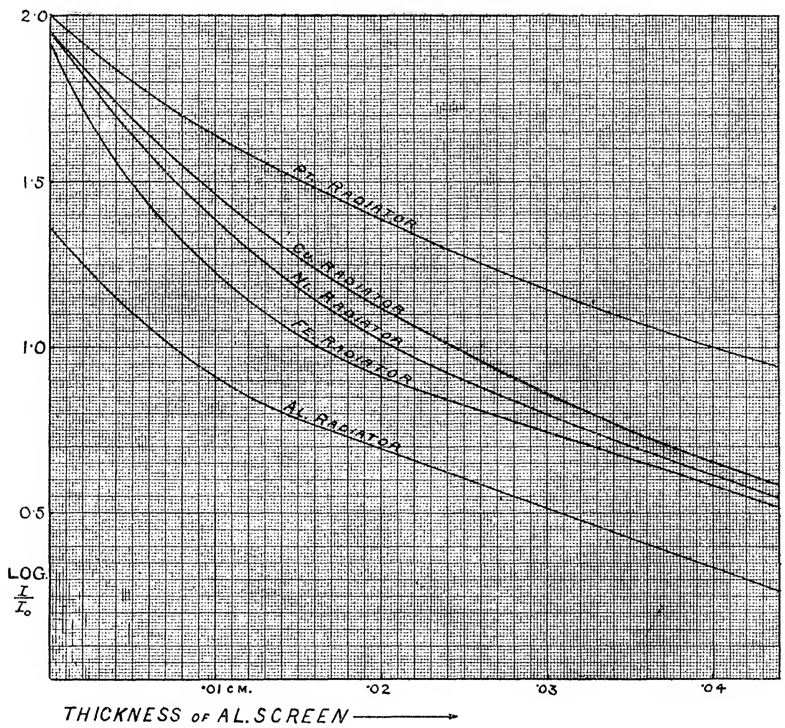


Fig. 7. Al screen, 20,000 volts.

It is the aluminium radiation that presents interest. The curve consists of an earlier steeper portion ($\lambda = 120$) which merges, when the screen attains a thickness of about 0·01 cm., into a straight line for the rest of its path ($\lambda = 40$). Throughout this latter region, then, the absorption is exponential, and the aluminium radiation behaves as if it were homogeneous.

*Copper Screens.*—If we inspect fig. 8, which embodies the results obtained with copper screens, we no longer see this indication of homogeneity on the part of the aluminium radiation. Instead, the curve presents the gradual diminution in gradient with increasing thickness of screen that is typical of Röntgen rays. It is now the copper radiation that appears homogeneous—its graph for screens thicker than about 0·0015 cm. is a straight line ($\lambda = 470$). For thinner screens the curve is a little steeper ($\lambda = 620$). The graph for nickel is very nearly straight over most of its path.

Iron and platinum yield normal curves like that of aluminium, but have a different range of $\lambda$'s. The nearness of the early parts of the curves for nickel and copper radiators will again be noticed. It is noteworthy that the radiation from platinum is

cut down by the thinnest copper screens, more than that from any of the other anticathodes. Only for screens thicker than about 0·0045 cm. is the platinum radiation more penetrating than that from copper. The platinum curve presently crosses the nickel and copper ones, and here the greater penetrating power of the platinum radiation becomes apparent.

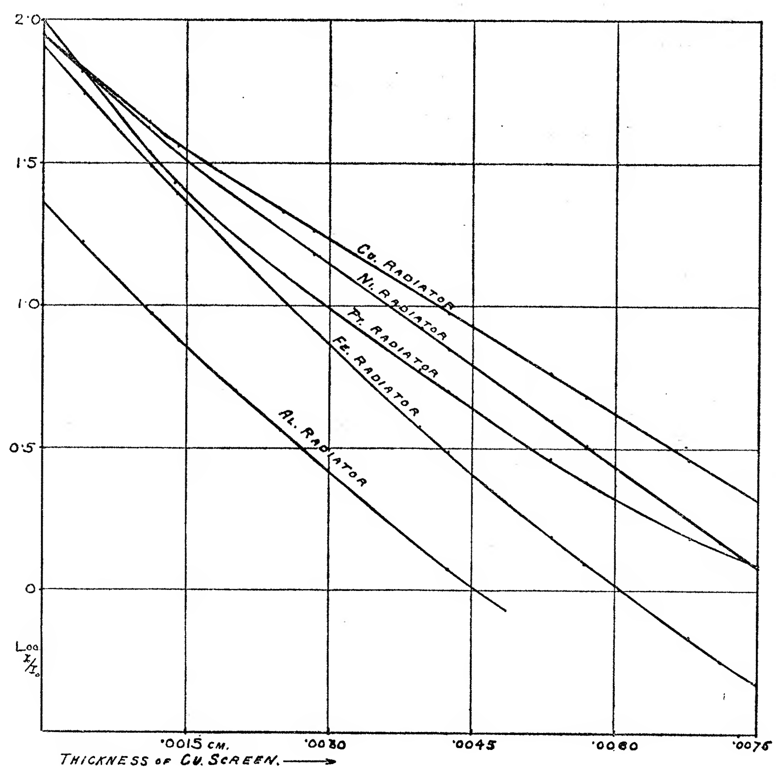


Fig. 8. Copper screen, 20,000 volts.

*Platinum Screens.*—We have noticed the apparent homogeneity of aluminium radiation with aluminium screens, and of copper radiation with copper screens, and we are led to expect a corresponding result for platinum. It will be seen on inspection of fig. 9 that such is the case. While the curves for copper, aluminium, and the other radiators are of the normal type, that for platinum is a perfectly straight line ($\lambda = 2350$) for screens thicker than 0·0004 cm. With thinner screens than this, the gradient is steeper ($\lambda = 3680$). Just as before, the earlier part of the nickel curve lies closer to the copper than to the iron curve.

The regions corresponding to the maxima in figs. 4, 5, and 6 will be noticed in figs. 7, 8, and 9.

*The Atomic Weight of Nickel.*—Repeated reference has been made (p. 134 and elsewhere) to the apparently anomalous behaviour of nickel, and it is here convenient to take up the lately discussed question of its atomic weight. BARKLA and SADLER,*

* BARKLA and SADLER, 'Phil. Mag.,' p. 408, Sept., 1907.

as mentioned above, claim a higher atomic weight—61·4—for nickel than the value 58·7 to which chemists give acceptance. The evidence the latter offer for the atomic weights of both nickel and cobalt (59) is so strong, that one hesitates to accept so big a change as Messrs. BARKLA and SADLER suggest. Their contention seems to rest on the following experiment. The secondary Röntgen radiations from Fe, Ni, Co, Cu, and Zn were cut down by a single screen of each of the following metals:—Al, Fe, Cu, Zn, Ag, Sn, and Pt. The percentage absorptions were plotted against the atomic weights of the radiators, and the points for the same screen were joined by a smooth curve (fig. 1, p. 410 in their paper).

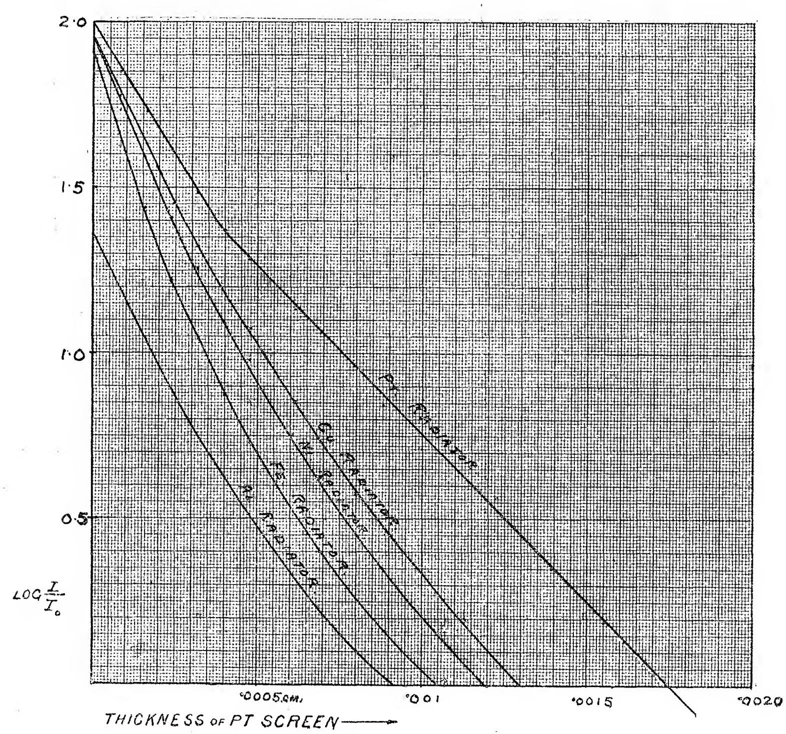


Fig. 9. Pt screen, 20,000 volts.

The curves for five of these screens indicate a value about 61·4 for the atomic weight of the nickel radiator; the curves for the other two screens (Cu and Fe) which exhibit selective transmission are not used. It is noteworthy that four of the five screens (Al, Ag, Sn, and Pt) have thicknesses which produce roughly the same amounts of absorption of the different radiations, so that any anomaly affecting the one screen might perhaps be expected to occur with the other three.

The rest of the paper deals mainly with absorption coefficients and "transparencies." These data are calculated from results obtained as above, by assuming the homogeneity of the different secondary beams—a general assumption admitted by the authors themselves to be dubious (p. 421).

I venture to suggest, on the lines of the results obtained in the present research on

primary rays, and on the evidence offered by Messrs. BARKLA and SADLER themselves (p. 412) as to the homogeneity of their secondary radiations, that such homogeneity is only rigidly true when screens and radiator have the same atomic weight or ones closely adjoining. If this be the case, the relative absorptions produced by any one thickness of a metal screen cannot safely be regarded as characteristic of the radiators; a screen of very different thickness would in general furnish another and a different set of relative absorptions.

Prof. J. J. THOMSON'S* anomalously high result for nickel in his work on Secondary Röntgen Radiation can, as he has pointed out, be equally well explained by supposing the radiation value for cobalt to be too low. This would be so if the cobalt (which was in the form of fine powder) were partly oxidised; recently, evidence was forthcoming that this was the case.

The results bearing on the point, obtained in the present work, are suggestive. From figs. 7, 8, and 9 (Al, Cu, and Pt screens respectively) mean absorption coefficients were obtained from the earliest portions of the curves (*i.e.*, the thinnest screens) for iron, nickel, and copper radiations. These are tabulated below:—

| Screen. | Radiator. | | |
|---|---|---|---|
| | Fe (56). | Ni (?). | Cu (63·6). |
| Al | 220 | 150 | 120 |
| Cu | 870 | 690 | 620 |
| Pt | 6800 | 5280 | 4720 |

For each screen the mean $\lambda$ for nickel radiation is nearer the $\lambda$ for copper than that for iron radiation, and each set of numbers plotted against atomic weight gives an atomic weight of almost exactly 61·4 for nickel.

But if we come to the last portion of the curves and work with thicker screens, and in a region which has been shown to be much freer from anomaly than is the case with thin screens, then we get different results. With both aluminium and platinum screens the absorption coefficients for iron, nickel, and copper radiators are almost identical ($\lambda$ about 40 for Al screens, and 3500 for Pt screens). Thus the absorption coefficients vary from those tabulated above for thin screens to a practical equality for thick screens. The method is therefore useless, at any rate in the case of primary rays, to evaluate atomic weights. With copper screens (fig. 8) the final portions of the curves are not yet out of the region of selective transmission, but it may be noted that the mean absorption coefficients for the thickest screens employed are $\lambda = 580$ for iron radiation, 540 for nickel radiation, and 470 for copper radiation—a set of values which makes nickel perfectly normal. Thus for thick screens, nickel offers no

* J. J. THOMSON, 'Proc. Camb. Phil. Soc.,' XIV., 1, p. 109, Nov., 1906.

anomaly either in the relative intensity of its radiation or in the relative absorption coefficients of different screens in dealing with its radiation.

The anomalous behaviour of nickel with thin screens appears to be due to the fact that the softer components of its radiation are considerably more penetrating than the softer components of the radiation from iron: possibly also the question of a different distribution of the rays comes in. If a similar result is true for the secondary radiations—and, judging from the many points of resemblance between the primary and secondary rays from the same metal, such an assumption would not appear to be altogether unwarranted—then Messrs. BARKLA and SADLER'S results can be completely explained.

It is worth noticing that KLEEMAN,* working with very hard incident rays ($\gamma$ rays from radium), found nickel perfectly normal in the intensity of its secondary radiation. HACKETT† measured the quantity of secondary rays produced by the $\beta$ rays from radium, and found that nickel took up a place just below cobalt, and one justified by its accepted atomic weight. DEWAR and JONES‡ have recently determined the vapour density of nickel carbonyl and confirmed the value 58·7 obtained by WINKLER (1893) and RICHARDS and CUSHMAN (1899) for the atomic weight of nickel.

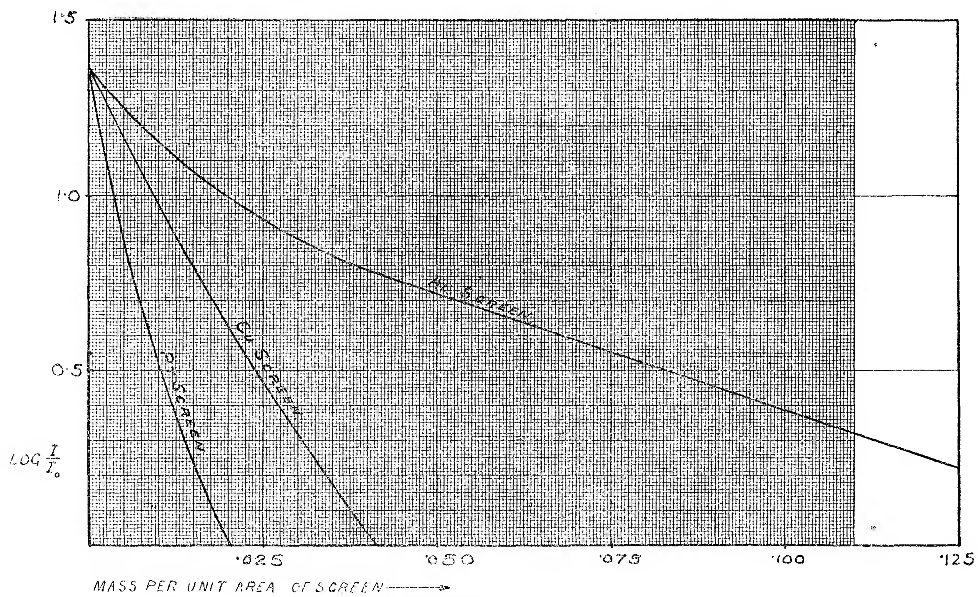


Fig. 10. Al radiator, 20,000 volts.

*Absorptions by Equal Masses of Screens.*—The interesting feature in the curves of figs. 7, 8, and 9 is the homogeneity manifested when radiator and screen are alike. Let us examine in turn the way in which the radiations from the metals aluminium, copper, and platinum are dealt with by screens of equal masses. In figs. 10, 11, and 12, $\log_{10}(I/I_0)$ is plotted against the mass per unit area of each of the screens.

* KLEEMAN, 'Phil. Mag.,' p. 618, Nov., 1907.

† HACKETT, 'Nature,' 75, p. 535, April, 1907.

‡ DEWAR and JONES, 'Proc. Roy. Soc.,' A, 80, p. 234 (1908).

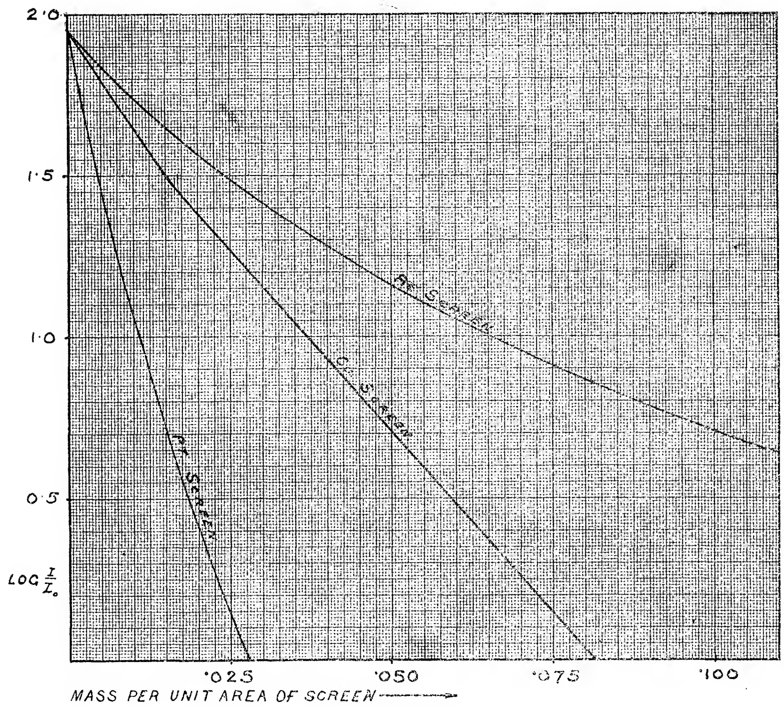


Fig. 11. Copper radiator, 20,000 volts.

Thus the slope of the tangent at any point on the curves gives (when multiplied by 2·3) $\lambda/\rho$ for that region, where $\rho$ is the density of the screen. The curves in each figure indicate the comparative effects of the three screens on the one radiation, and

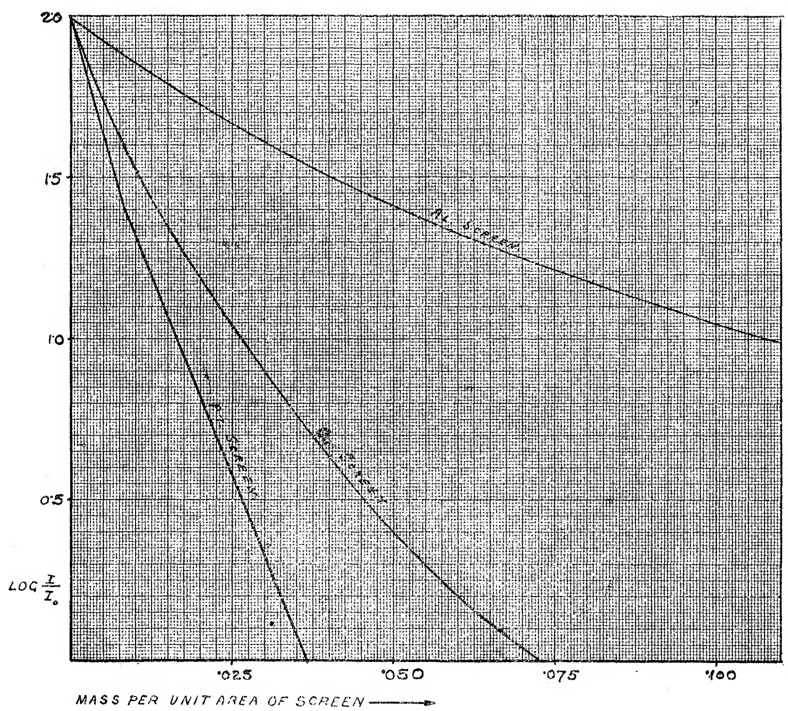


Fig. 12. Pt radiator, 20,000 volts.

once more display the homogeneity indicated when radiator and screen have the same atomic weight, and the lack of it when they are remote.

As previously mentioned (p. 123), BENOIST,* working with a definite beam of Röntgen rays, obtained a smooth curve, hyperbolic in form, by plotting atomic weights of screens against "coefficients of transparency" (*i.e.*, the mass of a prism of the substance of unit cross-section, which produces the same absorption as a standard prism, when the rays travel along the axis). Obviously the transparency (M) is inversely proportional to a mean $\lambda/\rho$ for the region of absorption, for $\log_e (I_0/I) = \text{const.} = \lambda d = \lambda M/\rho$.

BENOIST, using a platinum anticathode, obtained curves which yield the general result that $\lambda/\rho$ increases with the atomic weight of the screen,† and more rapidly in the region of low atomic weights: in other words, heavy atoms are more absorbent than light, weight for weight. The relative mean values of $\lambda/\rho$ below are taken from his curves to illustrate the point.

| | Screens. | | |
|---|---|---|---|
| | Al (27). | Cu (64). | Pt (195). |
| Hard rays . . . . | 4 | 36 | 100 |
| Soft rays . . . . | 10 | 75 | 100 |

If we examine fig. 12 (Pt radiator), BENOIST'S result appears at once from the relative slopes of the curves. But, from a general comparison of figs. 10, 11, and 12, it is obvious that the shape of BENOIST'S transparency curve, besides depending on the extent and region of the absorption, varies considerably with the radiator. As an illustration, the relative mean values of $\lambda/\rho$ for aluminium, copper, and platinum screens are obtained from the curves in figs. 10, 11, and 12, and tabulated below for the two cases when 50 per cent. and 10 per cent. of the radiation are transmitted.

| Radiator. | 50 per cent. transmitted. | | | 10 per cent. transmitted. | | |
|---|---|---|---|---|---|---|
| | Screens. | | | Screens. | | |
| | Al. | Cu. | Pt. | Al. | Cu. | Pt. |
| Al | 9 | 36 | 100 | 12 | 44 | 100 |
| Cu | 19 | 27 | 100 | 17 | 30 | 100 |
| Pt | 18 | 70 | 100 | 15 | 62 | 100 |

* BENOIST, 'Journ. de Phys.' (3), X., p. 653 (1901).

† The statement is also true for the soft $\gamma$ rays from radium. With hard $\gamma$ rays a "density law" holds and $\lambda/\rho$ is constant for different elements.

The fact is clear from the table that for the same radiator $\lambda/\rho$ is relatively low when screen and radiator are alike. With a radiator of copper (or any member of the Cr–Zn group) the effect is very marked, and BENOIST'S transparency curve would in this case be modified by the addition of a sharp maximum in the neighbourhood of the atomic weight of the radiator. BARKLA and SADLER* have obtained a similar result in the case of secondary Röntgen rays. With an aluminium anticathode and the potential used the transparency curve would be not very far from a straight line.

*The Initial Steepening of the Logarithmic Curves.*—The early steeper portion of each logarithmic curve of transmission when radiator and screen are alike has been noticed (figs. 7, 8, and 9). The extent of the steepening depends on the material of the screen.

An explanation which suggests itself is that the effect is due to the presence, in the radiation, of a certain amount of soft rays. If this were the cause, however, we should be able to eliminate the preliminary rapid decrease by placing between the aluminium window of the tube and the screen a sheet of some other metal thick enough to remove all the soft rays. This was tried with several metals, but always with the same result. Beyond small changes in the gradients no alteration in the shape of the curve was produced, and the kink still remained. In fact, if one gradually builds up a composite screen of a number of different metals, the logarithmic curve of transmission consists of a series of discontinuous steps made up of an initially steep and a subsequently flatter portion for each metal.

It is clear that the results are not due to the presence of any soft radiation, but we can find a ready explanation of the earlier steepness in the curves if we consider the effects of secondary radiation. At every stage the primary radiation transmitted by a screen is augmented by a certain amount of secondary radiation (in part softer than the primary) from the screen itself. For simplicity, let us consider the case of homogeneous primary rays. With thick screens none of the secondary radiation emerging on the far side of the screen comes from below a certain depth of the screen; that proceeding from greater depths is absorbed. Thus, in this region, the transmitted primary radiation is increased by a proportional amount of secondary radiation, whose presence does not conflict with an exponential law of absorption. But for screens which are thinner than this layer, the emergent secondary radiation, not having suffered the full absorption, is proportionately larger in amount relative to the transmitted primary. Consequently, until the screen attains a certain thickness, the intensity of the transmitted radiation will be relatively higher and the curve of transmission will be steeper than in the region of thicker screens.

This explanation is supported by the degrees of abruptness with which the steeper parts of the aluminium, copper, and platinum curves (radiator and screen being alike) merge into the subsequent slopes. BARKLA and SADLER† have shown that with soft primary rays, aluminium emits secondary rays similar to the primary in

* BARKLA and SADLER, 'Phil. Mag.,' p. 416, Sept., 1907.

† BARKLA and SADLER, 'Nature,' p. 344, Feb. 13, 1908.

hardness, but with harder primary rays such secondary radiation is replaced by one of a softer type. The absorptive power of aluminium is small, and we should expect the change from the steep part of the curve to the rest to be considerable, but gradual. This will be seen to be the case in fig. 7, where $\lambda$ gradually changes from 120 to 40 in a thickness 0·012 cm. of aluminium.

For copper and platinum the secondary radiations are much softer than the primary, and as the absorptive powers of the metals are high, we should expect, as figs. 8 and 9 show, a sharp alteration in the slope. With copper, $\lambda$ changes from 620 to 470 in a thickness 0·0015 cm., while $\lambda$ for platinum changes from 3700 to 2350 at a thickness 0·0004 cm.

It is of distinct interest to note that McClelland,* working on the absorption of the $\beta$ rays from radium by metal screens, obtained a similar steepening of his logarithmic curves of transmission in their early stages. His results for the ratios of the initial to the final slopes in the case of aluminium, copper and platinum are tabulated against the present values obtained for Röntgen rays.

| | Screens. | | |
|---|---|---|---|
| | Al. | Cu. | Pt. |
| $\beta$ rays . . . . . | 1·13 | 1·30 | 1·58 |
| X rays . . . . . | 3·0 | 1·32 | 1·60 |

The agreement with copper and platinum screens is certainly noteworthy. The lack of it with aluminium may be ascribed to the abnormal character of its secondary Röntgen radiation.

*Effect of the Potential Difference between the Electrodes.*—The next point investigated was the effect of a change in the potential difference applied to the terminals of the tube, on the apparent homogeneity indicated when screen and radiator are alike. Measurements were made at three potentials, about 8,000, 20,000, and 43,000 volts. The logarithmic curves of transmission with copper screens and copper and platinum anticathodes are given in fig. 13, where the three full-line curves stand for the copper radiation, and the dotted curves for the platinum radiation. For ease of comparison the initial intensities are made the same at all potentials for each radiator, though actually they were very different. It will be seen that the copper radiation is transmitted exponentially at both 8,000 and 20,000 volts; the only difference is that a rather lower absorption coefficient accompanies the higher voltage.

A departure from the exponential law is evident with thick screens in the curve for copper radiation at 43,000 volts. The range of indicated homogeneity becomes restricted, and the curve begins to display the features which characterise a normal transmission.

* McClelland, 'Sci. Trans. Roy. Dub. Soc.,' IX., p. 25, Feb., 1906.

The platinum radiation curves should be compared with the ones for copper under the same potential difference. An increase in potential lessens the difference between the early rates of absorption of the two radiations, and thus minimises the extent of the range during which the relative selective transmission of copper radiation by copper screens is manifested.

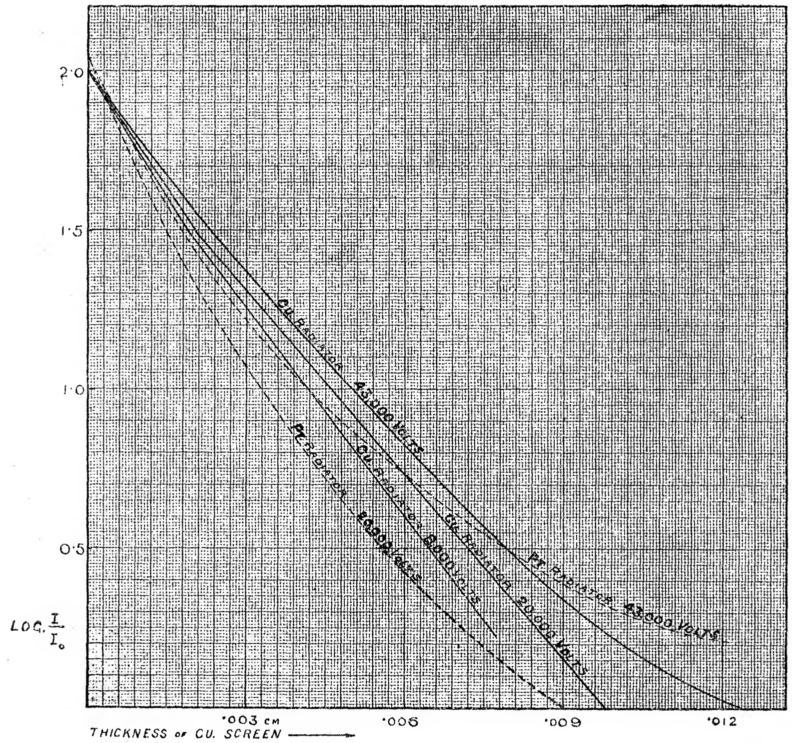


Fig. 13. Copper screen.

The curves also indicate the increased intensity (with thick screens) of the platinum radiation relative to that of copper which is brought about by using faster cathode rays (see also p. 135).

Thus the phenomenon of selective transmission shown by a metal depends very largely in its extent on the potential applied to the tube. Speaking generally, the lower the atomic weight the softer is the class of rays for which a metal exhibits the most marked abnormality.

## *Discussion of Results.*

The exponential absorption of Röntgen radiation when radiator and screen are alike, the gradual disappearance of such indication of homogeneity with a rise in the potential on the tube, and the entire absence of an exponential absorption when radiator and screen have remote atomic weights, receive explanation on Prof. J. J. THOMSON's theory of scattering. Scattering may be defined as the tendency of a beam, originally parallel, to become diffuse during its passage through a screen. Prof. THOMSON has shown ("Conduction of Electricity through Gases," 2nd edition,

p. 405) that the effect of scattering on the transmission of a homogeneous beam is to convert an exponential absorption into one in which the coefficients of absorption (reckoned on an exponential basis) diminish with the thickness of the screen. The larger the ratio of the energy scattered to the energy spent in ionisation of the absorbing substance the more will the absorption of the rays depart from an exponential law.

With a coil discharge cathode rays of widely varying velocities are incident upon the anticathode. From observations of the magnetic spectrum it appears that a considerable proportion of them have a common maximum velocity, at any rate when the potential on the tube is not very high. For a large number of particles we might therefore expect a typical mode of arrest, with features arising from the corpuscular groupings of the atoms of the anticathode. This being so, pulses of a definite type peculiar to the metal of the anticathode will form a large part of the Röntgen rays emitted.

It would be expected that pulses thus generated would suffer very little scattering on encountering further layers of a metal which presents atomic structures similar to those of the anticathode, and that the consequent diminution in intensity would be chiefly the result of ionisation. It must be remembered, too, that the rays are sifted to some extent before they emerge from the surface of the anticathode. When the atoms of the screens provide different corpuscular groupings to those in which the Röntgen pulses were generated, then the scattering effect will be pronounced, and the law of absorption of the beam would not be an exponential one, even if the beam were wholly homogeneous.

If the potential on the tube is increased, faster cathode particles impinge upon the anticathode, harder Röntgen rays are generated, and it will be these which remain when the thickest screens are used. Now the importance of the scattering term compared with the loss of energy due to ionisation of the absorbing substance increases with the hardness of the rays, and we thus have an explanation of why, even when screen and radiator are alike, the absorption falls away from exponential with higher potentials and thick screens.

It appears from the results that there is a considerable range in the hardness of the rays from an anticathode, for which a screen of the same metal will show an exponential absorption.

The fact that the intensities of similar hard radiations from different anticathodes follow the order of atomic weights and not that of densities, indicates for the cathode rays encounters which are dependent on the properties of individual atoms, and not on their behaviour *en masse* as a material. With heavy atoms a larger proportion of cathode rays would be expected to undergo arrests sufficiently abrupt to produce Röntgen rays than would be the case with lighter atoms.

It is not one of the objects of this paper to discuss the "neutral pair" theory of the Röntgen rays recently put forward by Prof. BRAGG, but seems to the writer

that it would be difficult, without some additional and special assumption as to the properties of a "pair," to explain on such a theory the marked transparency exhibited in the case of both primary and secondary rays when screen and radiator are of the same metal. The agreement in the order of the number of reflected cathode particles and the intensities of the accompanying Röntgen rays is also to be noticed.

## *Summary of Conclusions.*

The primary Röntgen radiations from some twenty elements have been investigated under various conditions.

(1) The relative intensities (measured by an ionisation method) of the radiations as they issue from the thin aluminium window of the tube do not follow the order of the atomic weights of the anticathodes. Such order shows agreement with that given by STARKE for the relative numbers of cathode rays returned by metallic reflectors. The intensities indicate a grouping of the elements which is identical with, and in features similar to, that arrived at by BARKLA and SADLER from a consideration of the secondary Röntgen rays.

(2) Over a certain region, when screen and radiator are of the same metal, selective transmission of the radiation is manifested, that is, the radiation from the metal is augmented relatively to the radiations from other anticathodes. The effect is also present to a less extent when radiator and screen have closely adjoining atomic weights. With very hard Röntgen rays, selective transmission is only feebly displayed. This is in accordance with the behaviour of the $\gamma$ rays which ignore atomic structure.

(3) This augmentation, when radiator and screen are alike, is most pronounced in the case of the metals of the chromium-zinc group. It is least marked for a substance of low atomic weight such as aluminium, which, of the metals tried, can be regarded as the most suitable screen material for measuring ray intensities.

(4) Speaking generally, the lower the atomic weight of a metal in a group the softer is the radiation for which it shows special transparency.

(5) If the different radiations are cut down by aluminium screens of increasing thickness, the intensities reach ultimate relative values which are not altered by a further increase in the thickness of the screen. Thus at this stage the rays from all the radiators are of the same quality or hardness. These intensity values are approximately proportional to the atomic weights of the radiators, and the two, when plotted, thus yield, roughly speaking, a straight line. The relative values of the heavy-atomed metals increase somewhat with a rise in potential on the tube. Screens of other metals eventually yield much the same sort of relation, modified slightly in the neighbourhood of the atomic weight of the radiator.

(6) When screen and radiator are alike, the absorption of unit mass per unit area of the screen (in other words, the ratio of the absorption coefficient to the density—$\lambda/\rho$)

is relatively low. One of the consequences of this is that the shape of BENOIST's "transparency" curve (which indicates that $\lambda/\rho$ increases with the atomic weight of the screen), besides depending on the range and degree of absorption, is largely dependent on the material of the anticathode. For example, the curve is much straighter for a radiator of aluminium than for one of platinum, working under the same conditions. With an anticathode belonging to the chromium-zinc group the transparency curve has to be modified by the addition of a sharp maximum in the neighbourhood of the radiator. BARKLA and SADLER have obtained a similar result in the case of secondary Röntgen rays.

(7) The question of the atomic weight of nickel has been discussed and an explanation put forward to account for the anomalous results obtained in connection with the secondary radiation from this element.

(8) The curve of transmission, in which the thickness of screen is plotted against the logarithm of the intensity, consists in general of three parts when radiator and screen are of the same metal. First, with thin screens there is a relatively steep portion, which for thicker screens is followed by a straight-line region: this, again, is ultimately succeeded by a region in which the slope gradually diminishes with the thickness of the screen. Corresponding to the straight-line portion of the curve there is, of course, an exponential absorption. The extent of this region diminishes with a rise in the potential on the tube. The preliminary steepening is attributed to secondary radiation: in amount, it agrees with that obtained for the same metal by McCLELLAND working with the $\beta$ rays from radium. The ultimate flattening of the curve is probably due both to scattering and to the presence of hard rays. This latter region may not be detectable if the potential on the tube is not too high, and the absorption curve then indicates homogeneity throughout its length.

(9) When screen and radiator have remote atomic weights, the region of exponential absorption does not appear. The early portion of the logarithmic curve is steepened by secondary radiation, but throughout the whole region the transmission is one in which the coefficient of absorption steadily diminishes as the thickness of screen increases. This result is probably brought about in the early stages chiefly by scattering, and in the later stages by the heterogeneity of the beam.

In conclusion, it may be remarked, the present research shows that the terms hard and soft rays should be confined to comparisons with screens of the same metal.

It gives me pleasure to thank Prof. THOMSON for his interest in this investigation. I wish also to express my indebtedness to Mr. E. EVERETT for his timely and ready assistance on occasion.

*Note on the Use of Tilted Electroscopes.*—As a good deal of time may easily be spent in adjusting a tilted electroscope to sensitiveness, it may be permissible to mention one or two points in connection with it which I have not seen dealt with elsewhere.

The point of support of the gold leaf should not penetrate more than a few millimetres within the case of the instrument. A useful length of leaf is 3·5 cms.; the end of the leaf should just swing clear of the charged plate when the instrument is tilted on end with the charged plate downwards.

It should then be found that with the base of the electroscope horizontal, and the charged plate at a potential in the neighbourhood of 200 volts, the sensitive region is near the middle of the window provided.

If the charged-plate end of the electroscope be tilted too high, and the potential on the plate too large, the leaf will be unstable over a part of its range, *i.e.*, it will not return to its zero when earthed. If considerable sensitiveness is aimed at, it is not a bad plan to first get the leaf in the unstable condition; then by means of the adjusting screws gradually lower the plate end of the electroscope, and at the same time diminish the potential on the plate until the leaf is stable and gives a region with the required sensitiveness. The greater the sensitiveness, the more limited the region of that sensitiveness—an extra volt on the charged plate, or a fraction of a turn of the tilting screws, may cause a large alteration in the sensitiveness.

With a short leaf, a large potential (240 volts or more) on the plate and an excessive tilt (the charged-plate end very high) will be necessary. A longer leaf takes a smaller potential (120 volts or so), and may require a considerable reverse tilt, *i.e.*, with the charged-plate end lowest.

If, when the potential of the leaf is altered, it creeps very slowly and uncertainly to its final position, it usually means bad electrical contact between the leaf and its support.